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**Investigation into Barbell Back Squat Comparing Weightlifting Shoes
to Barefoot Conditions**

Thesis submitted in partial fulfillment of Honors

By

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April 2016

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ABSTRACT

This present study was intended to investigate muscle activation patterns throughout the barbell back squat and determine if there are any differences found in EMG responses among individuals wearing weightlifting shoes and barefooted individuals. The hypothesis was that weightlifting shoes would generate significantly greater muscle activation patterns throughout the barbell back squat due to the rigid structure and raised heel in the shoe design. EMG patterns from six superficial lower extremity muscles were recorded from 12 subjects (means: 22.67 ± 2.39 age, 172.28 ± 14.04 cm height, 74.88 ± 16.11 kg mass), each meeting a specific inclusion criteria. Data collection occurred over three subject visits to determine one repetition maximum [1RM] (Day 1), conduct maximal contraction tests (Day 2), and finally to perform squat tests with the two footwear conditions (Day 3). Data was collected at 80% of the participants' 1RM utilizing both weightlifting shoes and barefoot conditions, and EMG activity was recorded for data analysis. Paired-sample T-tests were calculated to check for any significant differences among footwear conditions, and 2X2 ANOVA testing was used to determine if any significant changes occurred among footwear conditions in the eccentric and concentric portions of the barbell back squat. The study found two main components. The first was that several muscles showed differences between eccentric and concentric phases in regards to average muscle activity. However, none of the observed muscles showed significant differences between the two footwear conditions in regard to EMG activity.

INTRODUCTION

Barefoot training has increased in popularity tremendously within the past few decades. This increasingly popular fitness paradigm became apparent to most of the athletic population first among the running community. Circulating images of marathon runners completing road marathons with no shoes were presented through the media, and the paradigm began to gain interest among runners. The trend was soon sought after by well-established shoe manufacturers who began spending millions of dollars on research and prototypes to develop ideal minimalist running shoes. These shoes, ie. Five-finger shoes by Vibram™ (Concord, MA, USA), imitated barefoot biomechanics, providing a layer of protection against soft-tissue injuries for competitors. Athletes have approached this more “primitive” biomechanical basis with the belief that it decreases stress placed on body joints, and is more optimal for strengthening foot and ankle muscles. Some athletes even proclaim that the usage of standard running shoes increases the incidence of muscle atrophy in the foot needed for proper balance and proprioception (Perry, 2012).

Cross training has gotten exceedingly more attention since its implications on improving sport performance was discovered about 30 years ago. Cross-training is now popular in almost every sport, and consists of training for two or more sports at a time to improve fitness and performance components typically in a primary sport. For most sports, cross-training consists of strength training via resistance training. A plethora of research has been done looking at the benefits of strength training on athletic performance, and the benefits have led many coaches and athletes to incorporate strength training regularly into fitness programming (Beattie et al., 2014). Research has shown that implementing strength training into fitness programming has numerous benefits including: improved flexibility, ballistic movement, balance, proprioception, and

strength via improvements in the neuromuscular system (Lavallee and Mansfield, 2013).

Although the ideas of barefoot training and weightlifting had their own distinct origins, the two fitness paradigms can be seen incorporated together in modern fitness programming.

Research regarding barefoot individuals is an area of interest to modern investigators beyond the field of exercise and sports science as well. A recent study published in the *Journal of Foot and Ankle Research* investigated differences among gait biomechanics of flip-flops, sandals, barefoot, and running shoes. The results from this study indicate that certain areas of the foot are more prone to higher pressure than others. Therefore, some areas of the foot experience a greater amount of shear force capable of generating potential deformities and discomfort among patient groups (Zhang, Paquette and Zhang, 2013). This has led to the further advancements in foot orthotic technology and usage in preventative medicine. Other research has looked into the stability effects of barefooted individuals in comparison to shoed individuals (Nigg, Hintzen and Ferber, 2005). Electromyography (EMG) has been used by researchers on numerous occasions in collecting muscle activation patterns to develop conclusions regarding ankle stabilizer muscles (Dionisio et al., 2006). Similar studies have looked into areas such as taping techniques, sole construction, and rehabilitative protocols to determine the conditions needed for optimal ankle stability (Ozer et al., 2009), (Gu et al., 2014), (Clark and Burden, 2005).

Recent studies have looked at kinematic and kinetic changes in weightlifting form resulting from specially designed weightlifting shoes in comparison to standard athletic shoes (Sato et al., 2012). The weightlifting shoe is designed to have a noncompressible raised heel to promote adequate vertical and lateral stability for the lifter, whereas most standard athletic shoes are designed with compressible, flexible soles used for the absorbing excess force (Davis, 2012). These research protocols have focused on maintaining safe lifting form throughout the entire lift,

as well as generating maximum force output. A study done by Sato et al. (2012) investigated the kinetics and kinematics of the barbell back squat among athletes wearing weightlifting shoes compared to athletes wearing standard athletic shoes. The investigators looked for “excessive forward trunk lean” among athletes wearing standard athletic shoes. The excessive forward trunk lean adds unhealthy shear forces to the vertebrae of the lower back. The investigators found that the athletes wearing the specially designed weightlifting shoes experienced less forward lean compared to the standard athletic shoe group because the raised heel of the weightlifting shoes led to optimal pelvic rotation during the squat (Sato, Fortenbaugh, and Hydock, 2012).

Barefoot training studies have even led to advancements in rehabilitation programming. A systemic study by Behm and Colado (2012) investigated numerous studies regarding the effectiveness of resistance training using unstable surfaces and devices for rehabilitation. The authors began their study looking at the effects of instability training, and found that a predominant amount of research supports the incidence of significant force reductions with individuals performing force or power movements on unstable surfaces compared to stable surfaces, as well as compromises in movement velocity and range of motion. They thus concluded that, “The ability to exert force, power or move at high velocity is strongly related to an individual’s balance and stability when performing the task.” Secondary to the results in force production, the researchers also found that the muscle activation of antagonist muscles increased significantly when individuals trained on unstable surfaces. The increased contraction of antagonist muscles adds to joint stiffness, and ultimately joint protection. These findings support the usage of unstable surfaces in rehabilitation programming due to its benefit in treating muscle strains and sprains. The off-loading of force to antagonist muscles increases the integrity of the injured joint, decreasing the occurrence of further injury (Behm and Colado, 2012).

The purpose of this present study is to investigate muscle activation patterns utilized between two footwear conditions during the barbell back squat: weightlifting shoes and barefoot. It is hypothesized that the weightlifting shoe condition will generate greater muscle activation patterns in comparison to the barefoot condition, especially in the eccentric phase of the barbell back squat. It is believed that the weightlifting shoe condition will result in a greater vertical force production due to an increased amount of ankle stability. If the weightlifting shoe condition produces the greatest amount of force production, then the results can be used by coaches and athletes to further improve strength training protocols using weightlifting shoes.

LITERATURE REVIEW

A comment by the American College of Sports Medicine (ACSM) published in an article available on the organization's website regarding the safety of squat exercises has left researchers conducting studies to look at the potential areas of stress of squats on body joints, as well as the proper usage of the squat exercise in the workout protocol. It was once believed that the back squat was harmful to the knees and lower back of participants; however, the ACSM states that the causation of such injuries is not the squat exercise itself but the form of the individual partaking in the movement. A remark made by the ACSM says that, "Any resistance exercise improperly performed may result in injury." These injuries could be the result of excessive training volume, resistance, or improper form throughout the exercise movement (ACSM, 2015). To emphasize the importance of form in prevention of injury and the effectiveness of the squat exercise, the ACSM released a 12 point summary in regards to proper squatting form. This summary, and others like it, have led many researchers to look at the kinematics, kinetics, and muscle activation patterns utilized in differing squatting parameters. The most notable parameters for this study include footwear conditions, and the usage of stable and unstable surfaces in regards to vertical exercises and rehabilitation.

The support of studies aimed at understanding postural regulation is likely the origin of modern day research looking to develop a position focused on optimal footwear conditions for the most effective resistance training kinetics, kinematics, and muscle activation patterns. A study published in the *Journal of Physiology* by Kavounoudias, Roll, and Roll (2000) found that an individual's foot sole and ankle inputs both contribute to upright posture. These researchers looked at EMG responses of the tibialis anterior muscle and forefoot zones of both limbs during and after a proprioceptive or tactile stimulation to determine a pattern among feedback systems

among ankle stabilizer muscles. The researchers were able to find a trend among stimulation patterns that when the tibialis anterior muscles were proprioceptively stimulated via vibration individuals experienced a forward postural tilt and that when tactile stimulations occurred at the tibialis anterior muscles individuals experienced a backwards tilt (Kavounoudias, Roll, and Roll 2000). The application of this study to the current study is that activation of certain ankle stabilizers results in a shift in the center of pressure among the foot. This shift in the center of pressure can either increase or decrease ankle torque which could therefore decrease or increase the muscle activation response of ankle stabilizer muscles. The shift in muscle activation of ankle stabilizers would then contribute to a change in the muscle activation patterns an individual experienced at the knee joint.

Unstable surfaces are commonly generated via shoe modifications or the usage of rehabilitative equipment. Numerous studies have been conducted since the turn of the century looking at muscle activation patterns and postural sway with regard to different experimental parameters. Several studies have investigated these variables with subjects standing on unstable surfaces in comparison to stable surfaces. A commonly-cited project done by Nigg, Hintzen, and Ferber (2005) looked at the effect an unstable shoe construction would have on the gait characteristics among the lower extremity. The researchers compared the kinetics, kinematics, and muscle activation patterns throughout standing and walking among healthy individuals using an unstable test shoe and a stable control shoe (Nigg, Hintzen, and Ferber, 2005). The researchers used the Masai Barefoot Technology (MBT™), which simulates barefoot instability by its rounded sole providing anterior-posterior instability, and a cushioned heel providing medial-lateral instability. Subjects conducted three trials of standing with both feet on a force plate for ten seconds to develop data to determine the degree of anterior-posterior and medial-

lateral deviations in the center of pressure and a corresponding EMG activation. The results from the data showed that there was an increased amount of center of pressure deviation, a significant increase in the muscle activation of the tibialis anterior muscle, and further increases in muscle activations of the other tested muscles when using the MBT experimental shoe in comparison to the stable control shoe (Nigg, Hintzen, Ferber, 2005). These results support the idea that a balance training program has the potential to lead to increased muscle activity compared to conventional exercise protocols, and therefore indicates in regards to the current study that EMG activity of the barefoot condition and weightlifting shoe condition should differ due to the changes in ankle stability across the two parameters. The idea behind the technology is to “provide continual activation of important stabilizing muscles of the lower limb to maintain proper balance (Landry, Nigg, and Tecante, 2010).”

A second study done by the same performance laboratory was conducted looking at the affects an unstable shoe would have on postural sway and the muscle activation of specific smaller extrinsic foot muscles (Landry, Nigg, and Tecante, 2010). Once again the MBT™ shoe was enlisted to provide the experimental unstable condition, and a stable control shoe was used for comparison purposes. A barefoot condition was also used in this study to generate data to determine the effects it would have on the smaller extrinsic foot muscles. Subjects participated in each of the parameters during experimental testing, but were given a pair of the MBT shoes to wear throughout a six week trial period to determine any changes in the muscle activation patterns of the smaller extrinsic foot muscles. The experimenters hypothesized that due to the longer lever arms of the smaller extrinsic muscles across key foot joints that they would respond quicker to any changes in joint orientation. Therefore, increasing the incidence of joint

manipulation via instability would lead to an increase in smaller extrinsic foot muscle activation while standing in order to maintain posture.

The researchers once again used a force plate to determine any deviation in the center of pressure and an EMG to determine any changes in muscle activation patterns. The comparison of initial testing results and the end-of-trial testing indicated a significant difference in the EMG activity among the three experimental parameters, but on the MBT™ condition showed a significant increase in EMG activity when compared against itself after six weeks. The most prominent results collected were those of postural sway differences between the initial testing and end-of-trial testing. The center of pressure deviation recording measured among the MBT™ condition showed the greatest improvement (Landry, Nigg, and Tecante, 2010). Based off the results obtained in this study, the muscle activation of the smaller extrinsic foot muscles in this study should be higher in the barefoot condition compared to the weightlifting shoe condition. These studies, and many more like it, are the basis for further research conducted in regards to determining optimal lifting parameters for the most effective resistance training protocol that ensures safety, as well as the greatest muscle activation response.

The before mentioned studies looked at muscle activation patterns throughout the lower extremity during standing and walking. Dionisio et al. (2008) conducted a study that was published within the previous timeline investigating the kinematics, kinetics, and muscle activation patterns throughout downward squatting. The authors collected data regarding changes in center of pressure, ankle joint torque, knee joint torque throughout the squat movement via force plate, as well as, used an electromyography to explore EMG responses generated by nine lower extremity muscles. The authors discovered that the downward squat consists of two phases (acceleration phase and deceleration phase) that have specific effects on muscle activation

patterns due to changes in the kinematics and kinetics of the movement (Dionisio et al., 2008).

This study focused on the eccentric portion on a standard back squat to examine the stimulation of motor units from a clinical standpoint, which is the goal of the present study as well within the intended footwear parameters. The first intended observation is a shift in the center of pressure in the foot from the middle to the heel, followed by a shift of center of pressure to the toe, with the center of pressure returning back to the center of the foot at the completion of the downward phase. A second observation one would see is differences in overall muscle activation between the acceleration phase and deceleration phase of the downward squat. The researchers found that most of the acceleration phase of the downward squat can be attributed solely to gravity; therefore, muscle activation should be rather low during the acceleration phase and increase steadily during the deceleration phase (Dionisio et al., 2008).

In addition to these generalizations, ankle and knee torques should fluctuate as well. Researchers found that these torques are inverse, acting in opposite directions, to ensure optimal stability during the movement. The initial ankle torque will decrease as the knee torque increases during the acceleration phase. Likewise, the ankle torque will increase as the knee torque decreases during the deceleration phase. Unbalanced torque results in instability present in the downward squat (Dionisio et al., 2008). This study supports the hypothesis that muscle activation patterns in conjunction with the barefoot barebell back squat condition will result in less overall muscle activation due to inoptimal joint torques. On the other hand, there should be an increased muscle activation pattern correlated to the weightlifting shoe condition resultant because of the generation of a more opportune joint torque in the knee and ankle throughout the downward squat.

A second notable study investigating the eccentric phase of the barbell back squat was done by a group of specialists in Brazil. Alves et al. conducted a study investigating muscle activation patterns of key lower extremity muscles throughout ascending (70° - 0°) and descending (0° - 70°) portions of a standard squat compared to a declined squat (2009). The researchers collected data from eight subjects (3 men and 5 women) to analyze. The goal of the study was to isolate any significant imbalances in vastus medialis and vastus lateralis muscle activation between the standard squat and declined squat that are thought to be causative of patellofemoral pain syndrome. The researchers observed a difference in overall muscle activation throughout the movement with the standard squat modality compared to the declined squat. Secondary to these findings, a connection was also determined regarding tibialis anterior (TA) activation. The researchers discovered that initial TA activation did not occur with the onset of movement in the declined squat, and state this is due to potential mechanical disadvantages with the declined squat (Alves et al., 2009).

Researchers Anderson and Behm conducted a study investigating the possibility of increased trunk muscle activity with the utilization of unstable squat movements (2005). The protocol for this study involved fourteen male subjects squatting under three different stability parameters (balance disc, standard, Smith machine) and three different resistance intensities (body weight, weight of Smith machine bar, 60% participant body mass). Researchers looked at both the eccentric downward phase of the squat, as well as the upward concentric phase. The purpose of this study was supported by an already established idea that unstable training contributes to further develop neuromuscular adaptations that result in strength gains among participants. Therefore, the researchers believed that, “the inherently greater instability of the body-surface interface would challenge the neuromuscular system to a greater extent, possibly

enhancing strength gains attributed to neural adaptations” (Anderson and Behm, 2005). The researchers found an increase of muscle activity of abdominal stabilizers in regard to the balance disc trials compared to the other more stable experimental groups. The researchers also discovered that the soleus muscle and vastus lateralis muscle showed increased muscle activity among the same experimental group as well. As the resistance increased, all tested muscles showed greater muscle activation patterns, but the EMG recording displayed greater activity during the concentric phase compared to the eccentric phase. One significant observation Anderson and Behm were able to obtain in this study was that performing unstable squat movements can work to increase the actions of trunk stability muscles, and therefore not only have an effect on further development of designated movement muscles. It is possible that recognized movement muscles may not show much difference in muscle activation responses in unstable environments because they naturally have less of a role in postural stability and a variation in stability would therefore have little effect on any change in the typical muscle activation pattern elicited by that particular muscle group throughout the squat movement (Anderson and Behm, 2005). The results from this study could be used to support the data obtained within the present study. This study emphasizes that each muscle has a specific purpose and that not seeing an increase in lower extremity prime movement muscles could readily be witnessed within data collected comparing muscle activation patterns of lower extremity muscles during a barbell back squat with weightlifting shoes vs. barefooted.

Wobble board training has been used in the rehabilitation community for decades among clients diagnosed with functionally unstable ankles. Application of the wobble board mechanics has worked to strengthen ankles and prevent the reoccurrence of ankle sprains and other ankle injuries. Clark and Burden conducted a study to look further into an idea that ankle stability is

not solely due to a mechanical instability most of the time, but rather poor muscle activation response times. The researchers conducted a 4-week wobble board study with 19 participants to investigate muscle onset latency and the perceived stability among patients with functionally unstable ankles (2005). Previous studies have indicated the significance of proprioception when it comes to functionally unstable ankles. This proprioception, detection of stimulus, is mainly the result of mechanoreceptors within muscles that provide information to the central nervous system when muscles are stretched to initiate a feedback loop to prevent overstretching of the muscle and possible injury. The wobble board was designed to “assist the reeducation of the proprioceptive system by improving mechanoreceptor function and restoring the normal neuromuscular feedback loop” (Clark and Burden, 2005). Muscle activation patterns have been discovered to assist in the test of proprioceptive feedback loops by observing the quickness of muscle activation and the extent of muscle activation elicited throughout a various task. Therefore, the researchers used EMG responses to collect data that supports the usage of a 4-week wobble board program to combat functionally unstable ankles by aiding the proprioceptive feedback loop. The researchers used a 20° inversion test to determine muscle onset latency of the tibialis anterior and peroneus longus muscles before and after the 4-week training protocol, and found that both muscles had a significant reduction in time of onset latency (Clark and Burden, 2005). These results provide evidence regarding proprioceptive feedback necessary for joint stability.

Shoe instability is a growing area of interest among researchers investigating training parameters and rehabilitation protocols based on changes in the biomechanics of the lower extremity. Gu et al. recently conducted a study isolating the effects differing sole stability structures had on the kinematics and muscle response of the lower extremity (2014). The authors

believed that the purpose of shoes are to assist postural stability, and that shoes have an overprotection potential that results in muscle atrophy and injuries among the foot and ankle region. The researchers used this study to observe the function of instability in shoes to develop ideas for injury protection, postural stability, and balance. The design for experimental unstable soles stemmed from wobble board research, and mimicked the effects of MBT™ (Masai Barefoot Technology) and RC™ (reflex control shoes). The researchers collected data from gait cycles to determine levels of dynamic stability by analyzing kinematic differences and muscle responses throughout the observed gait cycle phase. Any changes in the gait cycle were believed to be the result of changes in lower extremity biomechanics due to sole modifications. The researchers designed the experimental shoes to modify the dispersion of pressure center through the alignment of unstable elements on the experimental shoes. The researchers found that manipulation of the pressure center resulted in changes to spatiotemporal parameters, plane of motion, and lower limb muscle activity. The results support the idea that slight changes to sole construction can have direct effects on ankle, knee, and hip kinematics, as well as lower limb muscle activity (Gu et al., 2014).

The purpose of weightlifting shoes is to protect the feet of lifters, to provide a stable platform and firm stance, as well as, to increase a lifter's degree of plantar flexion via a raised heel and noncompressible sole. Sato, Fortenbaugh, and Hydock (2012) recently conducted a study using 25 experienced weightlifting athletes that had been injury free for at least three months to investigate any kinematic changes in the barbell back squat when using weightlifting shoes compared to a control running shoe. This study was aimed to increase support for the weightlifting shoe providing safer lifting mechanics than running shoes due to the development of less forward trunk lean during the lift movement. Any excess trunk lean distributes shear

forces on the lower back that are causative of many injuries in the knee and lower back attributed to improper lifting mechanics. The authors discuss the potential for barefoot conditions to lack the initial plantar flexed origin of the weightlifting shoe that contributed to a greater foot segment angle thought to be the cause of greater muscle activation of knee flexors during the lift. The researchers found that utilization of the weightlifting shoe resulted in less forward trunk lean and greater knee flexor activity in comparison to using the running shoe (Sato, Fortenbaugh, Hydock, 2012).

The results from this study support that the degree of muscle activation developed in a lift are linked to the kinematics involved in the lifting movement. Foot segment angles will differ between a barefoot condition and weightlifting shoe condition like the before mentioned study. Therefore, the hypothesis of this present study is supported by the results of the study done by Sato et al. (2012) Differences should be seen in the comparison between muscle activation patterns of key lower extremity muscles of the barefoot condition to the weightlifting shoe condition in the study that support the usage of weightlifting shoes.

METHODS

Participants

All participants were healthy young adult population both male and female. The age range is from 18 to 24 years in both sexes. The demographic data is shown on table 1. The study protocol was approved by the University's Institutional Review Board, and the informed consent was obtained from all participants prior to participating the study.

All participants also met all inclusion criteria in order to participate in the study. The following criteria were set for the study; a) participants must be able to perform barbell back squat over 1.5 times of their body weight at one repetition maximum (1RM) and b) participants must have been instructed by certified strength coach in order to perform the back squat in correct technique.

Table 1: Demographic data of participants

	Total (N = 12)
Age (year)	22.67±2.39
Height (cm)	172.28±14.04
Mass (kg)	74.88±16.11
Estimate 1 RM (kg) with shoes	99.33±15.21
Estimate 1 RM (kg) with barefoot	91.50±20.21

Instruments

An 8-channel Noraxon TeleMyo 2400T (Noraxon USA, Inc. Scottsdale AZ) was used to collect maximum voluntary contraction (MVC) data and electrical activity of lower extremity muscles during the squat tests. Unit specifications included a differential input impedance of greater than 10 MΩ, a gain of 1000, and a common-mode rejection ratio of greater than 100 dB at 60 Hz. The EMG signals were high pass filtered with 10 Hz and low pass filtered with 500

Hz. The device was interfaced with its analog input/output 2400R G2 receiver (Noraxon USA, Inc., Scottsdale AZ). A bipolar Ag/AgCl surface electrode with an inter-distance of 2 cm was placed in parallel over the belly of tested lower extremity superficial muscles. Myosearch 2.11.16 software (Noraxon USA, Inc., Scottsdale AZ) was used for data processing and analysis. For the visual inspection of separating the eccentric and concentric phases of the back squat, a 60 Hz camcorder (Panasonic, Japan) was synchronized with the unit. Although motion of the squat was recorded to identify where the instantaneous point of concentric movement, motion analysis was not done according to the purpose of the study.

Data Collection

All participants were asked to meet three times for the study; 1) barbell back squat 1RM test, 2) maximum voluntary contraction (MVC) test, and 3) performing the barbell back squat with two footwear conditions (barefoot and WL shoes). It is important to note that each meeting was separated by at least 72 hrs to recover from the previous testing.

Day1: estimated 1RM squat test

Participants reported to the laboratory for the 1 RM test. Actual 1RM was estimated based on a 4-6 RM effort barbell back squat (Dohoney, Chromiak, Lemire, Abdie, & Kovacs, 2002; Sato & Heise, 2012). Warm-up consisted with dynamic stretching, 20 jumping jacks, and back squat with light weights and lasted a no more than 10 minutes. After the warm up, sets of 4-6 repetitions were performed until a maximum load was obtained for the 4-6 repetition trial. A minimum of 2 minutes rest was given between sets. The mean and standard deviation of the estimated 1 RM barbell back squat is listed in Table 1.

After the test, an identical 4-6 repetition maximum testing was completed with the barefoot condition. It is important to note that the reason for conducting 1RM test for barefoot

condition is to identify the 1RM for the barefoot condition assuming there would be different from the shoe condition. Another reason for this barefoot condition 1RM back squat test was also to eliminate possible overestimating the intensity during the barefoot squat on 80% of 1RM.

Day 2: MVC test

Participants reported to the athletic training room for MVC test. An isokinetic dynamometer (125AP, KinCom, TN USA) was set to isometric mode thus allowing participants to exert maximal force during the MVC test. Participants sat on the device with straps around the body to ensure the isometric contraction of tested muscles. First, the investigator prepared tested muscle locations by cleaning up skin and attaching electrodes. The sites for electrode placement were prepared by abrading the skin with fine sandpaper and cleansed with 70% isopropyl alcohol. Shaving excess hair was done if necessary for some participants. Dual disposable surface electrodes described above, were placed on selected superficial muscles to collect maximal electrical activity of each muscle.

A Noraxon TeleMyo 2400T (Noraxon USA, Inc. Scottsdale AZ) was used to collect maximum voluntary contraction (MVC) data and electrical activity of lower extremity muscles during the barbell back squat. Unit specifications included a differential input impedance of greater than 10 M Ω , a gain of 1000, and a common-mode rejection ratio of greater than 100 dB at 60 Hz. Raw signal was obtained at sampling frequency of 1,500 Hz. The EMG signals were high pass filtered with 10 Hz and low pass filtered with 500 Hz. The device was interfaced with its analog input/output 2400R G2 receiver (Noraxon USA, Inc., Scottsdale AZ). A bipolar Ag/AgCl surface electrode with an inter-distance of 2 cm was placed in parallel over the belly of tested lower extremity superficial muscles. Myosearch 2.11.16 software (Noraxon USA, Inc., Scottsdale AZ) was used for data processing and analysis.

For the visual inspection of separating the eccentric and concentric phases of the back squat, a 60 Hz camcorder (Panasonic, Japan) was synchronized with the unit. Although motion of the squat was recorded to identify where the instantaneous point of concentric movement, no images were used for data analysis.

There were total 6 electrodes attaching to 6 different muscles on one side of the lower limb (right side). Those muscles are 1) vastus medialis considered as medial quadriceps, 2) vastus lateralis considered as lateral quadriceps, 3) medial gastrocnemius, 4) lateral gastrocnemius, 5) tibialis anterior, and 6) peroneus. Electrode placement was determined according to the European Recommendations for Surface Electromyography 2nd edition (Hermens, Freriks, Merletti, Hagg, Stegeman, Block, et al., 1999). After placing all electrodes, participants sat in the dynamometer machine and were secured to the seat to exert an isometric contraction. Order of the MVC tests was 1) leg extension with knee angle at 90° (2 quadriceps muscles), 2) dorsiflexion with knee angle at 180° (anterior tibialis), 3) plantar flexion with knee angle at 180° (medial/lateral gastrocnemius), and 4) eversion with knee angle at 135° and ankle angle at 120° (peroneus). Maximal effort of contraction lasted 5 seconds, with the time between the 2nd to 5th seconds (3 seconds) considered as the maximal contraction. The two maximum attempts were averaged for the analysis. After the MVC test, all electrodes were removed and wiped with alcohol.

Day 3: squat test with two footwear conditions

Preparing the skin condition, identical approach was being made for the barbell back squat. Identical electrode placements were used for the squat EMG analysis with the other footwear condition.

The participants performed barbell back squat was at 80% of 1RM for 1 set of 5 repetitions in both footwear conditions. The two footwear conditions were randomly chosen for all participants. They started out with dynamic warm-up and then squatted with light weights leading up to 80% of 1RM intensity. The standard stance width was introduced for this study to a slightly wider than shoulder width and toes pointing slightly outward as described by Escamilla et al. (1998). All participants squatted down to a position where thighs are below parallel to the floor on each repetition. Participants were instructed to maintain the squat speed being relatively consistent between eccentric and concentric phase. In order to control the consistent rhythm of the squat, a metronome was used and set to 60 beats per minute (Sato & Heise, 2012). The current study used a slow-paced squat, and the participants were instructed to perform it with a rhythm of 3-2 count (3 counts downward 2 counts up). This rhythm was necessary to minimize unnecessary acceleration throughout the squat. A recent study found the influence of squat speeds on selected biomechanical variables (Hanson, et al., 2007). After completing 5 repetitions at 80% of 1RM, they placed the barbell back on the squat rack. The rest period between the set was 2 to 5 minutes depending on the participant's need.

Data and Statistical Analyses

As mentioned above, raw signal of EMG was obtained at sampling frequency of 1,500 Hz. The signal was rectified and converted to the average root mean square signal. Then the signal was smoothed using Hanning integrator set to 20 points. From each tested set of 5 repetitions the second, third, and fourth repetitions were considered for analysis by averaging the total of 3 repetitions. The back squat was separated into two portions; eccentric and concentric. The phase was divided by the lowest descent position of the squat visually identified from a recording device.

Upon the data collection, all data were exported to a spreadsheet for data analysis purpose (Microsoft Excel, WA USA). The average root mean squared EMG values of both eccentric and concentric phases of the squat in tested intensity (80% of 1RM) for each muscle were normalized as percentage based on the MVC values. Those percentage values were considered for the analysis of the current study.

To test whether there are differences 1) between footwear conditions and 2) between eccentric and concentric phases by 2x2 (footwear x phase) repeated measure ANOVAs were conducted on each muscle. The statistical analysis is performed by PASW software using alpha level of 0.05 (IBM Inc, New York, NY).

RESULTS

Table 2 is a descriptive data of the study outcome. There were statistically significant differences in phase (i.e., between eccentric and concentric) in five out of six muscles tested. However, there were no statistically significant differences in footwear condition (i.e., WL shoes and Barefoot) in all muscles. Even though interaction was not main focus of the study, the results showed interaction effect for medial gastrocnemius and peroneal muscles. All statistical results are summarized in the table 3.

Table 2

Descriptive Data: EMG Activation

WL Shoes						
	VastusMED	VastusLAT	MedGast	LatGast	AntTib	Peroneals
Eccentric	69.24±20.51	66.83±22.47	27.56±12.4 1	28.82±13.4 0	36.70±24.8 0	33.38±22.1 0
Concentric	122.62±39.3 7	112.09±24.7 1	45.62±24.8 4	44.51±26.5 5	28.73±8.36	48.66±25.1 6
Barefoot						
Eccentric	67.91±26.30	67.62±23.27	23.29±7.58	27.57±14.8 3	44.87±31.4 6	37.92±22.6 6
Concentric	136.33±33.0 6	114.08±31.5 3	40.78±20.4 8	37.75±18.5 6	28.16±12.5 1	46.92±24.7 7

*data is in millivolts (mV) and represents mean ± standard deviation

Table 3

Statistical Data: 2X2 ANOVA

	Main: Shoes	Main: Phase	Interaction
Vastus Medialis	$P = .184$	$P = .000^*$	$P = .222$

Vastus Lateralis	$P = .696$	$P = .000^*$	$P = .896$
Medial Gastrocnemius	$P = .218$	$P = .001^*$	$P = .914$
Lateral Gastrocnemius	$P = .133$	$P = .008^*$	$P = .268$
Tibialis Anterior	$P = .146$	$P = .082$	$P = .011^*$
Peroneaus	$P = .510$	$P = .002^*$	$P = .025^*$

DISCUSSION

Two main questions that are continually asked by athletes and coaches are whether or not lifting mechanics are safe, and if those mechanics are effective regarding the principle of specificity. The present study investigated the muscle activation patterns of six superficial lower extremity muscles throughout eccentric and concentric portions of a barbell back squat at 80% 1RM with the application of weightlifting shoes and barefoot conditions. The results showed that neither of the two footwear conditions observed in the study show a significant difference in muscle activation when compared to the other. Therefore, no significant changes occurred between the weightlifting shoe and barefoot conditions in regard to muscle activation patterns.

In regards to safety, exaggerated muscle activation patterns would indicate that mechanisms within the lifting movement are being compromised and are therefore less safe. The muscle activity patterns among weightlifting shoes and barefoot conditions were found to be similar among both eccentric and concentric portions of the barbell back squat. Therefore, although kinematic sequences may differ (Sato et al., 2012), EMG activation seems relatively consistent. A secondary consideration for the using weightlifting shoes vs. barefoot conditions during the barbell back squat would be the reduced anatomical protection of a barefooted individual in a weight room. The athletes would have less protection from weightlifting equipment, and would therefore have a higher chance of injury manifested by equipment. The results of the study find the EMG activity of weightlifting shoes and barefoot conditions equally effective and safe in regard to the barbell back squat at 80% 1RM. This means the effort level between the two footwear conditions were similar, thereby indicating that doing the barbell back squat barefooted may compromise the kinematics (Sato et al., 2012), but not muscle activation.

Although the findings of the present study do not support greater muscle activation among the individuals utilizing weightlifting shoes, secondary benefits could result from the application of this modality in comparison to barefooted conditions. A study previously presented in the literature review by Sato et al. (2012) found that weightlifting shoes were effective in preventing excess forward lean throughout the eccentric portion of the barbell back squat, thereby helping to prevent the development of lower back injuries among athletes (2012). This consideration should be weighed by coaches and athletes when developing an optimal fitness program.

The tibialis anterior muscle and peroneal muscles are both known to be contributors to dorsiflexion and eversion. The results of this study show that muscle activation patterns of both muscles were consistent among both weightlifting shoes and barefoot conditions. This supports the usage of both methods for improving muscle activation patterns of the tibialis anterior muscle and peroneal muscles among rehabilitative programs and sports performance to assist in greater ankle stability among individuals.

The purpose of this experiment was to look at muscle activation patterns, not muscle force production. The MVC testing done on day 1 was to make sure that all participants were comparable to one another. Weightlifting shoes offer more ankle stability than barefooted conditions so the participants were able to physically lift more with weightlifting shoes than when barefooted due to greater force production. This was the major reason for finding the participants' one repetition maximum on day 2 of testing. Knowledge of the 1 RM allowed testing to occur at a percentage (80%) of that value for consistency among footwear parameters. The results found that at 80% 1RM there were statistically significant differences in phase (i.e., between eccentric and concentric) in five out of six muscles tested. However, there were no

statistically significant differences in footwear condition (i.e., WL shoes and Barefoot) in all muscles.

CONCLUSION

Future studies regarding muscle activation patterns of weightlifting movements among differing footwear conditions should continue to investigate both eccentric and concentric portions of the lifting mechanic. Both phases of the lift have been determined to indicate key differences in kinematics, and could be useful in providing evidence for the effectiveness of one modality over another. Increasing the number of subjects within the study would lessen the standard deviation, thereby increasing the integrity of the results as well. Coaches and athletes are interested in obtaining the greatest results within the shortest amount of time while maintaining safety, so determining one methodology as more effective and safer than another will contribute heavily to exercise prescription in the future.

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